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Development of Nonlinear Ultrasonic Techniques to Assess the Microstructural Damage of 0.1% and 1% Fe-Cu Steel

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The US fleet of operating light water power reactors has entered the first period of life extension, and components will see more neutron exposure and duty cycles than were originally anticipated, particularly as the Nuclear Industry develops technical bases for a second period of life extension (operation to 80 years). Therefore, it is very important to develop methods of detecting microstructural damage that occurs in these nuclear reactor pressure vessels (RPVs) from chronic radiation exposure. During irradiation, there are several parameters that can cause the microstructural damage that leads to embrittlement. One of these parameters is the formation of copper-rich precipitates (CRPs) in the RPV steel during radiation exposure. This research investigates the generation of the second harmonic in longitudinal waves through the thickness of Fe-0.1% Cu steel and Fe-1%Cu steel as well as in Rayleigh surface waves along the surface of the same Fe-0.1% Cu steel and Fe-1%Cu steel specimens containing Cu nanoclusters (simulated radiation damage). Recent studies have shown that nonlinear ultrasound (NLU) is sensitive to microstructural changes in materials [1,2,3]. This research will expand this knowledge on the sensitivity of NLU and can be used in the future for a better characterization of radiation damage and the remaining life of RPVs. The specimens used in this research were heated treated for varying amounts of time using the same schedule that was used by Park et el. [4]. This variation in heat treatment times simulates varying amounts of radiation damage by the formation of copper precipitates. The CRPs interact with existing dislocations generating ultrasonic nonlinearity that is measured with both longitudinal and Rayleigh waves. Using the measured volume density of CRPs and dislocations, the ultrasonic nonlinearity is predicted and compared with the experimental data. This experimental and theoretical study can then be used to correlate the amount of copper precipitation and the degree of embrittlement which will be very useful in lifetime prediction of RPVs.

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